Northern Arabian Sea Circulation – Autonomous Research (NASCar) DRI: A Study of Vertical Mixing Processes in the Northern Arabian Sea

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LONG-TERM GOALS

This study contributes to our long-term efforts toward understanding:

- The dynamics of barrier layers and surface mixed layers in the N. Arabian Sea

- The penetration of radiative and atmospheric fluxes into the ocean interior

- Interaction of finescale and submesoscale processes in barrier layer formation

- Characteristics and impact of internal gravity waves trapped above barrier layers

OBJECTIVES

This project is a study of vertical mixing processes in surface boundary layers and subsurface barrier layers of the Northern Arabian Sea (NAS) using Large Eddy Simulation (LES) techniques and turbulence-parameterizing Second Moment Closure (SMC) models, both as column models and implemented in a regional circulation models. The goals of this study are to develop a better understanding of upper-ocean vertical mixing of heat, salinity and momentum, and to provide an improved basis for modeling these processes in ocean circulation models and coupled ocean-atmosphere models.

APPROACH

LES and SMC techniques are used to predict mixing both within and vertically adjacent to the halocline separating the surface mixing layer and the subsurface barrier layers in the NAS. Simulations include both processes of formation through vertical forcing and horizontal advection across a salinity gradient, and also the evolution of layers through processes of turbulent vertical mixing and internal wave dynamics. An important focus is the testing and implementation of improved turbulent mixing parameterizations in conjunction with LES modeling, autonomous field observations, and regional-scale operational and process modeling, focused on predicting the response to surface forcing.

Numerical methods. For turbulence-resolving simulations, this study is modifying the NCAR LES (Sullivan and Patton, 2011) standard code provided to Harcourt by Peter Sullivan of NCAR. Although its physical model is substantially similar to the LES used in prior research (e.g. Harcourt, 2008) the NCAR LES code offers significant advantages in both the numerical scheme and in scalability on massively parallel computer architectures. Using this code for complex problems through entails modifications that are guided by prior work. For parameterizing turbulent mixing processes, this study is both implementing and further developing the Harcourt (2013; 2014) SMC of Langmuir turbulence, which introduces significant modifications of stability functions due Craik-Leibovich forcing, and uses an additional near-surface momentum flux closure term proportional to the the gradient of the surface wave Stokes drift.

Vertical mixing formation processes. Turbulence-resolving LES of surface-forced LES across a range of forcing parameters will quantify the role of surface waves in the initial formation of barrier layers. These simulations are forced by surface wave model products or approximated as duration or fetch-limited. Both monsoonal rains and diurnal shortwave heat fluxes at $O(1)$ kW/m^2 play a large role in modulating vertical mixing in the Arabian Sea, and the competition between these stabilizing forcings and Langmuir turbulence is strongest between $O(1)$-$O(10)m$. Correctly predicting SST effects due to these near-surface dynamics may bear significantly on the skill of coupled air-sea models and predictions of seasonal climate processes.

Advective layer formation processes. LES models of baroclinic mixed layers are combined with vertical mixing simulations to examine how formation depth scales and layer growth are impacted by the stratifying effect of differential advection across frontal salinity gradients. Parallel SMC modeling tests the skill of ocean model boundary mixing parameterizations to accurately represent these formation processes. Simulations target the NAS areas of barrier layer formation near salinity fronts, using variable forcing that represents monsoon wind, waves, buoyancy heat flux and precipitation conditions.

WORK COMPLETED

Numerical modeling during FY14 (since funding began in June, 2015) has included LES modeling of barrier layer formation by vertical processes, examination of the trapping of gravity waves above barrier layers, and progress on the implementation of the Langmuir turbulence SMC in the COAWST version of the ROMS regional ocean model, which includes coupling to the SWAN surface wave model and the WRF atmospheric model. LES runs carried out on DoD HPC resources have included simulations of the formation of barrier layers by vertical processes of restratification by monsoon rains, and some examination of the dynamics and impact of the trapping of internal gravity waves at the top of barrier layers under both steady and inertially resonant wind forcing. Further development of the SMC model has completed coding the new closure into ROMS model subroutines, including new and more accurate 'realizability' constraints on the algebraic closure and stability functions. Testing of the SMC of Langmuir turbulence implemented in ROMS, and completed tests in stand-alone column form show these constraints make the model more robust under variable forcing conditions. Work in the coming year is expected to complete testing of the ROMS SMC implementation, and carry forward LES runs to cases for predicting diurnal NAS SST variations and the formation of barrier layers by lateral restratification in baroclinic mixed layers.

RESULTS

Simulations of barrier layer formation under the combined forcing of freshwater flux from monsoon rainfall and wind forcing using the SMC of Langmuir turbulence show significant impacts from the inclusion of Craik-Leibovich forcing from surface waves (Figure 1). Restratification against the wind stress forcing alone leaves a barrier layer more than 20% thicker than in the simulation that includes surface wave forcing. Similar impacts from the added effects of surface waves are expected for barrier layer formation by lateral processes in LES and ROMS models modified for Craik-Leibovich forcing.
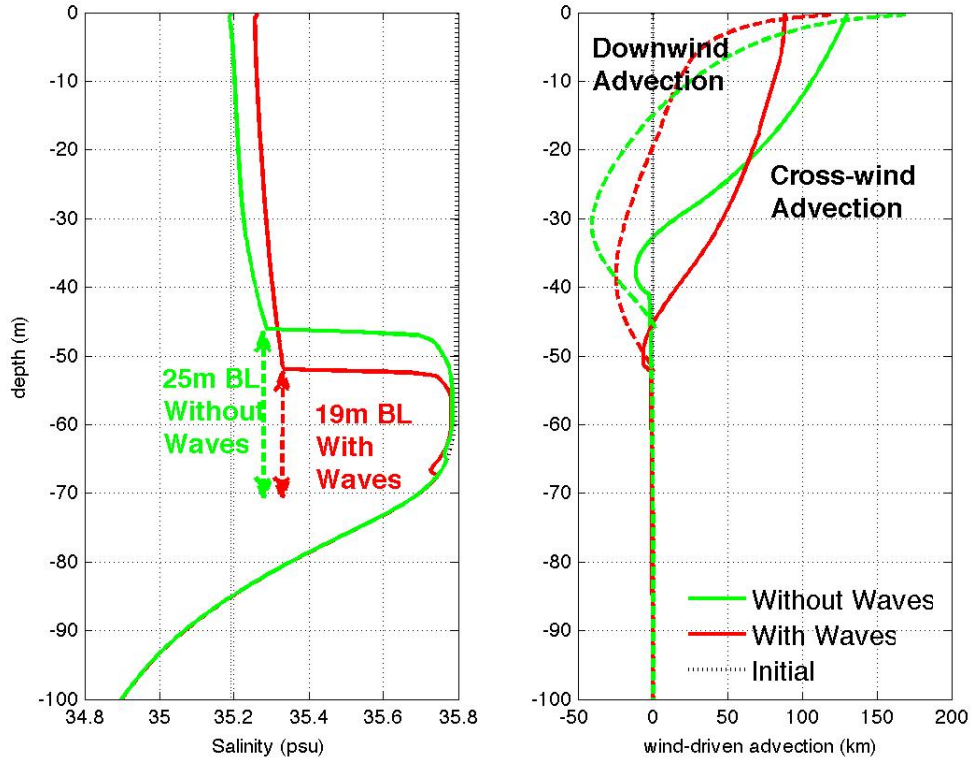

Fig. 1 SMC simulations of barrier layer formation by vertical mixing forced by rain and wind. Initial and final Salinity profiles (a, left) after 1 week of forcing by 14.8m/s of wind and 5 mm/hr of rain, both with (red) and without (green) Langmuir turbulence effects from fully developed seas. Thickness of final barrier layer (BL) indicated (left). Integrated horizontal distances advected in the downwind (dashed) and cross-wind (solid) directions (right), including the Stokes drift in the case with waves.

Weakly stratified barrier layers below an actively entraining surface mixed layer may marginally impact entrainment of the upper layer by trapping gravity wave energy at the interface between the two well-mixed layers, energy that might otherwise radiate downward and drive subsurface mixing over a broader range of depths. As examined in Polton et al. (2008), the generation of these waves may be intertially modulated, reaching a maximum when the bulk mixed layer current is to the right of the wind. Additional mixing that is driven by the trapping of these waves is illustrated by the LES modeling results shown in Fig. 2.
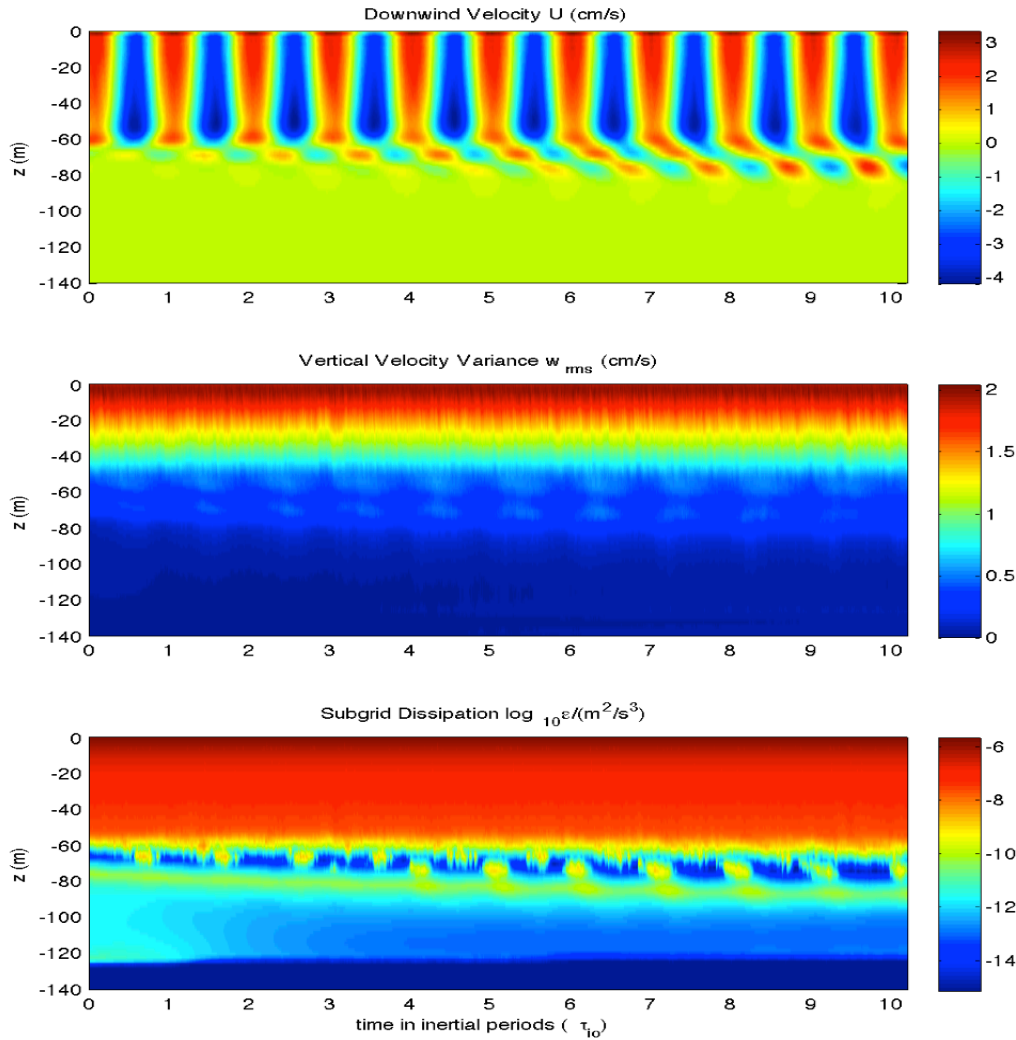
Fig. 2 LES of upper ocean response to a step function in wind to U_{10} =10m/s at t=0. Without near-inertial wave radiation or slab model damping, velocity in the mixed layer above 60m (upper) rings at the inertial frequency above a barrier layer extending rom 80 to 130m depth. Vertical turbulent kinetic energy of gravity waves trapped on the on the pycnocline between 60-80m depth (middle) is inertially modulated, with maxima when the bulk mixed layer velocity is perpendicular to Langmuir roll structures in the mixed layer. LES subgrid dissipation maxima are largest when the inertial current is to the right of the wind, but also shows maxima when to the left of it.

IMPACT/APPLICATIONS

NASCar DRI results bear on the predictive skills of regional scale models, particularly in areas with barrier layer formation. While accuracy in predicting these layers bears on the skill of coupled atmospheric models that depend on SST, progress in understanding the finescale and submesoscale processes of their formation will have broader impacts on ocean modeling skill.

RELATED PROJECTS

None.

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